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System Design and Specification

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DISCLAIMER

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Introduction

I am both an administrator and a researcher, and therefore come with an entirely different persuasion than the previous speaker. I believe there is no longer such a thing as a minicomputer; all so called mini's are getting to be fairly large with respect to computational, control, and memory capabilities. In the future, all progressive laboratories will use many micro- and minicomputers in distributed and hierarchical networks to support instrumental analysis, experimentation, and distribution of information. A number of such systems are now in various stages of design and construction. My interest is in the type of system that can give me all the time-response and bandwidth characteristics required for advanced instrumentation, experimentation, and process control, as well as perform computations generally restricted to batch processing on medium and large computers.

Four or five years ago I thought that participation in a workshop such as this was something that would not be required in 1978. At that time we were working hard on development of procedures for system specification and design of complex computer systems.[1-6] We hoped that by developing more standard procedures and by documenting working examples we could provide the necessary general guidance for the design and construction of new systems.[7-24] Obviously we were wrong.

Many years ago, in the mid-60's, we at LLL started with an empty computer and built a real-time, time-shared system for instrument control, data acquisition, and data reduction. Out of that experience I became convinced that to build a good laboratory system that meets the real-time requirements, has the desired bandwidth characteristics, and supports imaginative experimentation, you had to begin by carefully defining and specifying the desired system before the selection of specific hardware! Otherwise, it is very difficult, if not impossible, to cost-effectively implement the desired system. In the late 60's, I investigated a number of failures in laboratory and process automation, including million dollar projects, and found that in every case of failure the system had not been properly specified nor designed before the computer hardware was acquired. The scientists and engineers had spent the bulk of their time and effort on hardware selection, without the benefit of system specifications and designs.

System Specifications

One definition of specifications is: the listing of those myriad details necessary to direct the uninformed in the construction, installation, and testing of a complex project. For automation of chemical instrumentation and experimentation, some of the elements of the system specifications are: the transfer function of the instrument, instrument control function, digital signal processing algorithms, environmental conditions (temperature, electrical noise, and humidity), and any chemical procedures relevant to the automation. In short, when developing specifications and designs "think systems".

In addition to the above items, management practices are very important if you are building a distributed or a time-shared system of any kind. As one simple example, sample identifications and reporting procedures in very large systems can be one of the more difficult aspects of the automation. If you do not carefully analyze and characterize such procedures, design and implementation of the software is extremely difficult.

There are many elements of the system to be automated that should receive careful attention before selection of specific hardware. However, because automation is so complex and requires the expertise usually found in several diverse scientific and engineering disciplines, it is very difficult to readily generate a set of specifications. Why not, then, treat automation like other complex problems, i.e., separate the variables into manageable domains? There are many ways of separating the variables so the designer can readily develop specifications and designs. One method that we found useful and which has been generally adopted by ASTM Committee E-31, is to begin by first partitioning the system into three domains, i.e., inputs to the system, outputs from the system, and the transfer functions that interconnect these two.

Inputs. Inputs to an automated system are any stimuli that can or in fact do evoke a response from the system. Inputs include signals from instruments, transducers, terminals, environmental noise (electromagnetic radiation, and light sources, when photosensitive transducers are used), and transient noise on power lines. Environmental conditions such as humidity, temperature, and rate of temperature change can also act as inputs often stimulating the system so as to invalidate data or in worst cases result in total system failure.

When developing system specifications these various inputs should be characterized so the designer can assure system immunity to unwanted signals and design for complete recovery of the desired information from relevant signals. For example, complete characterization of the analog signals from instruments and transducers must be included in the specifications. This includes the time response, bandwidth, and noise characteristics. Time response for a required action is the time that elapses between the need for the service and the time the service is complete. As an example, for many simple data acquisition tasks the time response is the time elapsed between the clock-initiated CPU interrupt and the time the analog-to-digital conversion is complete. In other cases, where the information from an instrument or transducer is being used for control purposes, the time response might include the above time plus the time required to execute the control algorithm, initiate a change in control, and the time required for the system to reach the new (or safe) condition. In short, time response is often a crucial characteristic that must be carefully specified if very accurate information or time-precision control is required.

Signal bandwidth specifications define the frequency components of the analog waveforms that contain the useful information. Given these specifications, appropriate data rates can be established for accurate signal reconstruction and analysis of noise-free signals. Because signals from instruments always contain noise, signal bandwidth characterization must include analysis of the noise frequency and intensity. Given good specifications of the instrument noise and the signal containing chemical (or other) information, the designer can include in the design the appropriate analog and/or digital filtering required to remove the noise without distorting the desired waveform. If this cannot be accomplished, a new or redesigned instrument must be used.

Outputs. The outputs are the system responses to inputs (stimuli). They require the same kind of considerations discussed for inputs. The output specifications should be organized so as to support design procedures, a stepwise consideration of types of outputs would include such things as whether they are digital or analog, their time response characteristics, required data rates or bandwidths, human engineering considerations, environmental conditions, and the grounding requirements.

Transfer functions. A transfer function can be considered as an algorithm that describes how an output is obtained from one or more inputs. One method of describing transfer functions is by flow charts and timing diagrams. These various functions will be executed by means of both hardware and software. The exact trade offs between hardware and software implementation techniques principally depend upon the data rate requirements, time-response characteristics, and execution times of software algorithms; i.e., computer speed and algorithm design.

Functional designs. Functional designs are graphic representations of the data paths connecting the inputs, transfer functions, and outputs. They correspond to the architect's blueprints. On many pathways it is desirable to include the required data rates and time response characteristics.

Procedures

The above gives a brief overview of the extent of specifications required for the automation of complex systems. Developing specifications is by far the most difficult task one must perform before any system is operational. Therefore, the most cost-effective procedure is to complete these before selecting specific hardware. An operational procedure that we use and one that has been adopted by ASTM is shown in Table 1.

Table 1. Operational procedures.

Definition
System specifications
Functional design
Implementation design (hardware and software selection)
Implementation
Test and evaluation
Documentation

We recommend that one begin by writing a tutorial definition of what is to be accomplished by the automation. This document should include the main objectives and goals of the effort, such as improved through-put and/or accuracy, improved experimental capabilities, better analysis and associated reports, etc. It should also include a cost-benefit analysis, which can only be included after completion of the System Specifications and Functional Designs and completion of at least preliminary implementation designs.

For complex automation projects the development of specifications and design followed by implementation and testing is an iterative process as shown in Fig. 1.

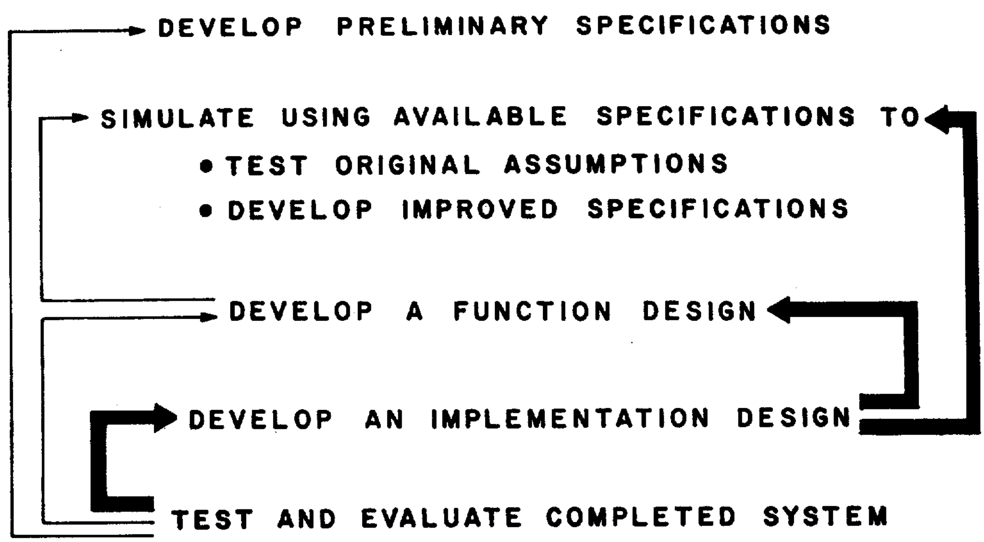

FIGURE 1 PROCEDURES FOR DEVELOPMENT OF COMPLEX CHEMICAL MEASUREMENT SYSTEMS REQUIRING MULTIPLE INSTRUMENTS

If one follows the procedures briefly discussed above and in the referenced literature, one finds that while complex automation is difficult, it is not only possible but manageable and generally cost-effective.

Summary

The foregoing was a very brief discussion of a procedure many have found helpful in the design and implementation of complex automation projects. The many references cited discuss the philosophy and evolutionary stages that accompanied the development of more standard procedures. In addition, case histories in the form of complete sets of specification etc. are referenced.

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